This invention concerns a process and an apparatus for generating an inert gas under superatmospheric pressure and at a desired rate, which gas is suitable for injection into an earth formation.

There are many processes in industry in which an inert or substantially inert gas is required at an elevated pressure. For example, such a gas is desirably utilized in repressurizing formations of oil wells. Although the process and apparatus of this invention can be utilized to produce gas for other purposes, the process and apparatus will be described in connection with formation repressurizing.

The gas required for formation repressurizing should be inert or substantially inert to avoid explosion hazards and to minimize corrosion of equipment. Actually, the gas need not be inert in the sense of a rare gas (e.g., helium), but it must be virtually non-oxidizing under the existing conditions, virtually free of acid-forming components and virtually free of any other corrosive components. As used herein, the term "inert gas" refers to a gas which contains virtually no oxygen and which is relatively non-corrosive under the conditions in which it is utilized. For example, a gas containing by volume less than 5 parts per million oxygen, about 89 to 90% nitrogen, about 10 to 11% carbon dioxide, and not over 10 parts per million oxides of nitrogen, is usually considered in the oil industry to be an inert gas.

The most practical system for producing inert gas at elevated pressures involves burning hydrocarbons in an internal combustion engine to form an exhaust gas which will inherently contain undesirable components (such as nitrogen dioxide), converting the undesirable components in the exhaust gas by reaction in a catalytic converter, and compressing the inert gas in a compressor driven by the internal combustion engine. However, in some cases the power required to compress the inert gas to the desired pressure is insufficient to cause enough fuel to be burned in the engine to generate the necessary volume of inert gas. Using a leaner fuel mixture is not a satisfactory solution because this results in excessive oxygen in the final "inert" gas stream. Another solution which has been proposed is to draw a high enough vacuum at the compressor suction to yield the additional horsepower consumption required to produce the desired gas volume. However, such a vacuum system is subject to leaks which contaminate the gas with oxygen from the air. It has also been proposed to burn additional fuel in a separate furnace but this requires extra equipment, making the cost of the over-all unit excessive.

It is therefore an object of this invention to provide an apparatus and method for generating and providing inert gas at an elevated pressure by the method of catalytic conversion of engine exhaust gases wherein the volume of gas can be adjusted to yield in excess of that which would normally be generated due to power used in compression alone.

Another object is to provide such an apparatus and process where such volume can be adjusted by a simple mechanical adjustment which can be readily made in the field.

Other objects, advantages and features of the invention will be apparent from the specification, claims and drawings wherein:

FIG. 1 is a schematic diagram showing an arrangement of apparatus in accordance with this invention and one with which the process can be practiced, and

FIG. 2 is an illustration of a variable pitch fan hub which can be used as part of the apparatus of this invention.

The apparatus there shown comprises an internal combustion engine 10 having its exhaust gas passing to a catalytic converter 12 where corrosive and generally undesirable components of the exhaust gas are converted by reaction in the presence of a catalyst to non-corrosive or at least more desirable components. The gas after reaction in the catalyst converter 12 passes to an air-cooled cooler 14, preferably on to a separator 16 for removing condensed water from the gas, and then on to a compressor 18.

Each of the air-cooled coolers 14, 24, and 28 is shown to be provided with a fan, such as fan 32 on cooler 14, fan 34 on intercooler 24, and fan 36 on intercooler 28, which blows air over cooling coils to cool the substantially inert gas flowing through the coils. In actual practice in the design of a compact unit, coolers 14, 24 and 28 will be stacked so that a single fan will be used which will blow air over the coils in each of the coolers. However, for the sake of simplifying the drawings, the coolers have been shown separately.

Each of the fans 32, 34 and 36 (or the single fan mentioned above) is driven by the internal combustion engine 10 through a drive system schematically represented by dashed lines 38 and 40. At least one and preferably all of the fans 32, 34 and 36 are provided with means for varying the pitch of their fan blades. Such means can take a variety of forms, one of which is illustrated in FIG. 2. Thus the engine drive shaft 38a is connected to fan hub 38b and the blades 38c are received in a bolted clamp 38d so that by loosening bolts 38e the blade can be rotated to another pitch and then reclamped by tightening the bolts.

Each of the compressor stages 18, 20 and 22 are also driven by the internal combustion engine 10 as represented by the dashed lines 44, 46 and 48. The separators 16, 26 and 30, which may be constructed in the form of scrubbers, accumulators, and the like, include drain traps 50, 52 and 54, respectively, to permit the water removed by the separators from the passing gas stream to leave the system.

With the foregoing arrangement, it will be seen that if the engine fuel consumption required to drive the compressors is insufficient to produce the desired volume of
inert gas, the pitch of the propeller blades can be increased to correspondingly increase the fuel consumption until the required amount of inert gas is produced. Therefore, the required additional inert gas can be obtained simply by adjustment of the pitch of the fan blades without any change in the discharge pressure of the last compression stage or in the suction or inlet pressure to the first compression stage.

In addition to providing the necessary additional inert gas, there are other advantages to this arrangement. For example, the increase in blade pitch causes air to flow over the cooler tubing at much higher velocities. The resulting increase in efficiency per square foot of tube area results in the size of the coolers thereby resulting in a savings in cost of equipment. Also, the pitch can be adjusted in the field to compensate for variations in horsepower consumption due to altitude, different types of fuel, etc.

To better illustrate the foregoing, let it be assumed that a unit is to be provided which will deliver inert gas at about 1000 p.s.i.g. If the unit were designed to deliver 178,000 cubic feet per day, the compressor would take only about 95 horsepower for its operation. However, an engine using natural gas in developing this 95 horsepower would only result in the production of approximately 25,000 cubic feet per day. By adjusting the pitch of the fan blades so that they require about 25 horsepower to drive them this is enough extra horsepower to make the 178,000 cubic feet per day of inert gas delivered out of the compressor at 1000 p.s.i.g.

A hydrocarbon fuel supply 56 supplies fuel to the internal combustion engine 10 and it also can supply a small amount of sparger fuel as required to the inlet end of the catalytic converter 12. Engine 10 is operated so as to keep the oxygen in its exhaust down to a practical minimum and since all engines have some unburned fuel in the exhaust, this fuel will frequently be sufficient in quantity to consume the exhaust oxygen by combination in the catalytic converter. However, in those cases where the fuel in the exhaust is insufficient to consume the exhaust oxygen, additional hydrocarbons can be added in the form of sparger fuel to effect this oxygen consumption. Thus, a combustion analyzer 58 controls a valve 60 which in turn controls the flow of sparger hydrocarbon fuel to the catalytic converter 12. If the quantity of oxygen as measured by the combustion analyzer 58 is too high, a quantity of hydrocarbon sufficient to provide a slight excess of oxidizable material over the amount of available oxygen present will reduce the oxygen content of the substantially inert gas to a very low value.

As indicated above, it is very undesirable for the first compressor stage to draw a vacuum on the system upstream from it. In the system of the present invention, a positive back-pressure is always maintained on the engine exhaust manifold and normally this will be 10 to 12 inches of water and should not exceed 20 inches of water. By satisfactory design of the converter 12, cooler 14 and separator 16, the first compressor stage can have a positive suction pressure, e.g., 2 inches of water. In achieving this relatively small pressure drop between the engine exhaust and the first compressor stage suction, one of the prime considerations is the pressure drop across the catalyst "bed" in converter 12. In the present arrangement, the catalyst is disposed on long, thin strips of metal and these are arranged in a desired manner so that while the gas is not uniformly exposed to the catalyst, the pressure drop across the mass of metal strips is maintained at a minimum.

Catalysts for this type of reaction are well known in the art and are available in the market place. A preferred catalyst comprises finely divided platinum disposed on "Inconel" strips.

The hydrocarbon fuel for engine 10 is preferably natural gas or propane, but other fuels can be used.

The apparatus and process for this invention have been used to produce satisfactory inert gas. For example, under normal operating conditions, the following percentages by volume of dry gas will be produced:

| Oxygen | Less than 5 p.p.m. |
| Carbon dioxide | 10–11% |
| Oxides of nitrogen | Not over 10 p.p.m. |
| Nitrogen | 88–89% |

Other inert gases, e.g., argon, helium, carbon monoxide, etc. | About 1% |

From the foregoing, it will be seen that this invention is one well adapted to attain all of the ends and objects hereinbefore set forth, together with other advantages which are obvious and which are inherent to the process and apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described what is claimed is:

1. An apparatus for manufacturing substantially inert gas, under superatmospheric pressure and at a desired predetermined rate, said apparatus comprising a hydrocarbon-fueled internal combustion engine wherein exhaust gas is formed; a catalytic converter communicating with said engine for accepting said exhaust gas and converting corrosive components thereof to form a substantially inert gas; cooling means for cooling said substantially inert gas; said cooling means comprising a fan driven by said engine, means for varying the pitch of the blades of said fan to thereby control the power consumed by the fan and hence the power output of said engine and accordingly the rate of exhaust gas produced by said engine whereby the rate of exhaust gas produced by said engine approximates the desired predetermined rate; and a compressor driven by said engine and communicating with said cooling means for accepting said substantially inert gas therefrom, said apparatus from said engine to the compressor creating a positive back pressure at the engine of approximately 12 to 20 inches of water whereby the inert gas at the compressor will be slightly above atmospheric pressure, said compressor compressing it to a superatmospheric pressure.

2. The apparatus of claim 1 wherein said cooling means is an atmospheric cooler and said fan is positioned to cause air to flow through the cooler to cool the inert gas flowing therethrough.

3. An apparatus for manufacturing substantially inert gas, under superatmospheric pressure and at a desired predetermined rate, said apparatus comprising a hydrocarbon-fueled internal combustion engine wherein exhaust gas is formed; a catalytic converter communicating with said engine for accepting said exhaust gas and converting corrosive components thereof to form a substantially inert gas; cooling means for cooling said substantially inert gas; a plurality of compressor stages driven by said engine and accepting said gas from the cooling system for pressuring it to superatmospheric pressure; an intercooling means interposed between adjacent compressor stages; said cooling means and said intercooling means including fans driven by said engine, and means for varying the pitch of the blades of the fans to thereby control the power consumed by the fans and hence the power output of said engine and accordingly the rate of inert gas produced by said apparatus whereby the rate of exhaust gas produced by said engine approximates the desired predetermined rate.
4. The apparatus of claim 4 wherein said cooling means and said intercooling means employ the same variable pitch fan.

5. The apparatus of claim 1, wherein a fuel line having a valve communicates with the converter and a combustion analyzer communicates with the exhaust of the converter and the valve whereby sparger fuel may be added to the exhaust to consume any unconverted oxygen in the converter.

6. The apparatus of claim 1, wherein a separator for removing condensed water is located between the cooler and the compressor.